ANTHROPOGENIC MODIFICATION OF THE PHYSICAL ENVIRONMENT ASSOCIATED WITH URBAN LAND USE CONVERSION

Joshua D. Curley and Ray Lougeay
Department of Geography
State University of New York
Geneseo, New York 14454

ABSTRACT This study was conducted to analyze urban climatologic modification associated with desert development and changing land use. Specifically, an analysis of surface temperature, as portrayed on thermal remotely-sensed imagery, was compared to current land use in regions of rapidly expanding urban landscape near, and including, Phoenix, Arizona. Modern techniques of remote sensing and geographic information systems (GIS) have been employed to extract surface climatic information related to various biophysical land use categories of the present and future. In the context of global change, land use projections for the future are used in constructing regional scale climate projections employing the proposed study's findings. Use of these projections will be made in developing strategies for studying possible future land surface induced climate change in this, and other, desert regions. The focus of this article is to assess the magnitude of anthropogenic earth surface change, and associated magnitude of climatic modification.

In recent times, the Phoenix, Arizona Metropolitan area has experienced phenomenonal human-induced physical alterations. The rapid conversion of land from agricultural and desert uses to commercial and residential uses is a feature of these changes. It was hypothesized that climatic modifications have occurred in recent years as a function of these land use conversions. Because of this, Metro Phoenix became a logical and appropriate location to conduct a study which attempts to determine the extent that anthropogenic activities--land use conversion in particular--have affected the urban climate.

In Spring, 1992 an ongoing climatological project which is funded by the National Science Foundation and conducted jointly by geographers from Arizona State University and State University of New York College at Geneseo was initiated. The field research for the study was conducted in the Phoenix area. A pilot study, also centered in Phoenix, was done in 1989 which laid the ground work for this year's project. Initial observations and a focused goal were established for the 1992 effort during the pilot study. The current project's goal is to determine whether land use modifications cause climatic changes in the boundary layer environment. And, if so, to develop predictions and theories as to the extent that any changes may occur in the future based on the findings. In order to determine if the land use conversions are causing climatic changes in Metro Phoenix, several methods of data gathering were employed.

METHODS OF DATA EXTRACTION

A network of weather stations, known as PRISMS sites, are permanently gathering climatic data in Greater Phoenix. These small weather stations, 20 in all, measure the near surface and air climate on several parameters. Every five minutes, around the clock, measurements of temperature, precipitation, relative humidity, wind speed, wind direction and atmospheric pressure are recorded at these sites. These randomly located sites are situated in various land use types, but are all located within electrical substations.

A second source of data used in the study came from a series of mobile transects which covered many of the neighborhoods in Metro Phoenix. These mobile data recorders determined the air temperature every block or so along several transecting routes. Desert, agricultural, residential, commercial and the urban downtown areas of the Salt River Valley were included in the transects.

Temporary fixed climate stations were positioned at three sites representative of the three distinct biophysical land use types found in the Phoenix area. These stations recorded 15 parameters of the surface, air and sub-surface climate around the clock. These parameters included: incoming and outgoing solar radiation, thermal emittance, net radiation, air temperature at the surface, .5 m, 1.5 m and 3 m, relative humidity, wind speed and direction, soil heat flux at -10 cm and -2 cm, etc. An assortment of instrumentation and numerous levels of climatological measurements were dealt with in the field. An irrigated lawn site with substantial biomass was chosen to represent the irrigated agricultural lands and irrigated residential lawns of the Valley. A desert site which consisted of sparse xerophytic vegetation and a bare, rocky surface was the second locale. This site represented the indigenous landscape of the Salt River Valley of central Arizona. An asphalt lot functioned as an example of the third main land use type in Phoenix. The lot represents the commercial, industrial and highway land uses--each of which exhibits a paving of the natural terrain.

While decidedly representative of most of the land in the Phoenix area, the three sites--irrigated, desert and asphalt--were selected on the basis of their topography, homogeneity and size. A flat topography was imperative in order to avoid solar radiation inaccuracies through shadows, slope and exposure. Imagery that was used had the Greater Phoenix area topography masked out when data analysis was completed to avoid data distortions. A homogeneous block of every area was necessary to insure accurate data for each site. The avoidance of surrounding land uses' influence was remedied for the most part by the large size of each area. The substantial size was also a requirement for the target site to appear larger than a single pixel of LANDSAT thermal imagery.

The remotely-sensed LANDSAT Thematic Mapper imagery was used to depict surface temperatures. The digital values of Thematic Mapper band six (10.5 to 12.5 microns) provided by the imagery data for individual pixels were converted into temperature values. These pictures and the calculated pixel temperatures were then used in conjunction with GIS processed land use maps provided by the Salt River Project, the major utility company in Metro Phoenix. By comparing the heat factor for each 120 m by 120 m pixel from the satellite imagery with the determined land use description provided by the Salt River Project (SRP) it becomes possible to calculate the temperature of each land use category. This information when applied with the raw climatic data pumped out by the various ground stations in the region can then be utilized to formulate theories and predictions for climatic changes based on SRP predictions for land use changes in the future.

GROWTH OF METROPOLITAN PHOENIX

It is the fast rate of expansion in an area as large as Greater Phoenix that makes the Salt River Valley unique. This rapid expansion also makes the comprehension of the changes that land use and climatic processes have caused and have the potential to cause all the more critical, particularly since over half of the land use conversion is from irrigated agriculture to urban. In terms of human population expansion, Metro Phoenix has grown from a 1970 population of 971,000 to a 1990 population of 2.1 million. This 20 year growth rate of more than 110 percent places Phoenix as the fastest growing of the top 30 American urban areas. Perhaps even more noteworthy is the Maricopa Association of Governments (MAG) predictions that Metro Phoenix will reach 4.0 million inhabitants by 2010 (Maricopa Association of Governments, 1985). All the while even this extraordinary figure has been criticized as underestimating growth. While past growth has been sprawling, the SRP predicts that future growth will also take that route by converting still more land to urban uses and squeezing another 2.0 million people into the Salt River Valley in the next 20 years.

It is obvious that with the population explosion and the accompanying urban sprawl, there will be land use changes. According to SRP land use maps, in the next 20 years residential uses will increase by about 30 percent while commercial and industrial uses will nearly double. All this growth in the urbanized areas Greater Phoenix must come at the expense of other land uses. Not surprisingly, the dense biomass tracts and natural desert regions are the areas being converted. Agricultural uses such as cotton, citrus and vegetable fields are being pushed further and further from the city. At the same time, desert lands have practically been eradicated from the region altogether. The only remaining patches of natural desert are found on protected reservations. The SRP projections for the future show the continuation of these trends--the conversion of agricultural high biomass land uses and indigenous desert uses to commercial, industrial and dense residential uses.

CLIMATIC OBSERVATION

Phoenix was chosen as the study site for this project for a number of reasons. The Salt River Valley is a region for which abundant climatic data has already been gathered. The climatic processes have been thoroughly examined in this region for decades and provide a useful base to compare current climatic information to the information collected in the past. The thoroughness of the data gathered is evidenced by the PRISMS network. Also, Phoenix was the logical location for a study involving satellite imagery because of its reliable clear weather. Furthermore, The Salt River Project has meticulously detailed the land uses of the entire region. In addition, the Phoenix area was chosen because it provides the best example of a rapid growth area and offers a remarkable case of land use conversion. And lastly, as a desert metropolis, Phoenix offers a unique case of a fragile region which is very susceptible to climatic variation.

In order to sufficiently understand the climate of Metro Phoenix, the project chose a "typical" summer 24-hour period to do extensive data gathering. This way, the project draws information from both day and night conditions for a more complete assessment of the urban desert climate. After processing all the climate data extracted on the ground, Idrisi processed land use maps supplied by SRP were combined with Erdas processed thermal images of the area taken by LANDSAT satellites to get the whole picture of land use changes and climatic changes in Metro Phoenix.

DISCUSSION

Dense vegetation, such as an irrigated field of crops, a park or a lush residential plot have a distinct effect on the climate of the immediate surroundings. In the desert just as anywhere else, the importation of water to these "green areas" for the livelihood of the vegetation increases the evapotranspiration occurring in the area. Basic climatology tells us that when dense vegetation exists, nearly

70 percent of the solar energy which would normally be transformed into heat is expended for evapotranspiration. This, in turn, retards the heating process. In areas where there is very little biomass, such as the natural desert and urbanized areas, much more of the solar radiation budget can be utilized in the warming process. Other major land factor that effect the local climate are the albedo and the surface specific heat. Different surfaces have varying abilities to reflect and absorb incoming radiation. In Metropolitan Phoenix areas with asphalt surfaces, common in the commercial and industrial core and in most residential area, the bulk of the incoming radiation is absorbed and the subsequent heat is held at the surface. Between albedo, heat retention and evapotranspiration, near surface temperatures may vary considerably depending on the land use characteristics. And thus, land conversion has the potential to change the climate significantly in a localized area.

This project's preliminary results showed a remarkable disparity between different land use regions. Data showed that at midday, irrigated surfaces had a temperature of 39-44 degrees Celsius, commercial and urbanized areas measured 51 degrees Celsius and desert surfaces recorded temperatures around 54 degrees Celsius (Lougeay and Brazel, 1991). At night, both the irrigated and desert terrains cooled off rapidly while the urbanized surfaces' drop in temperature was both delayed and less dramatic.

Knowledge of the heat island effect in Phoenix has been acknowledged for a long time (Balling and Brazel, 1986). Balling and Brazel (1989) have observed that the urbanized area of Phoenix is approximately 3 degrees Celsius warmer than the largely agricultural lands surrounding it. During recent decades, the Phoenix Area Heat Island has grown in size to include many of the suburbs and has increased the disparity between Heat Island temperatures and surrounding land temperatures. The most blatant climatic change that has occurred in the Salt River Valley is the increase in daily minimum, or nighttime temperature. The loss of agricultural lands and the coinciding urbanization of the Valley are believed to be the causes (Balling and Brazel, 1989). A study completed last year by the Arizona Office of Climatology detailed the strong correlation between mean annual temperature and the population of Greater Phoenix over the past several decades (Balling, 1992). With the projected growth rate, this analogous warming trend can only persist.

CONCLUSION

Climatic change is one of the hottest subjects of contemporary climatology. The public becomes most excited about the yet unproven theory of the Greenhouse Effect. Whereas most scientists have come to embrace the Greenhouse Effect as a credible assumption, it has progressed no further to this date and the debate persists. Nevertheless, Greenhouse Effect proponents say the global temperature may increase by one to three degrees Celsius in the next several decades. While this should concern everyone, the potential for heating within the urban realm is much greater. As we hope to show empirically with work on this project, the conversion of land use in such rapid growth desert communities such as Phoenix, Arizona may have an even greater impact on nature. Perhaps this will prove to be something which cannot be ignored for long.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant Number SES-9122524.

ENDNOTES

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